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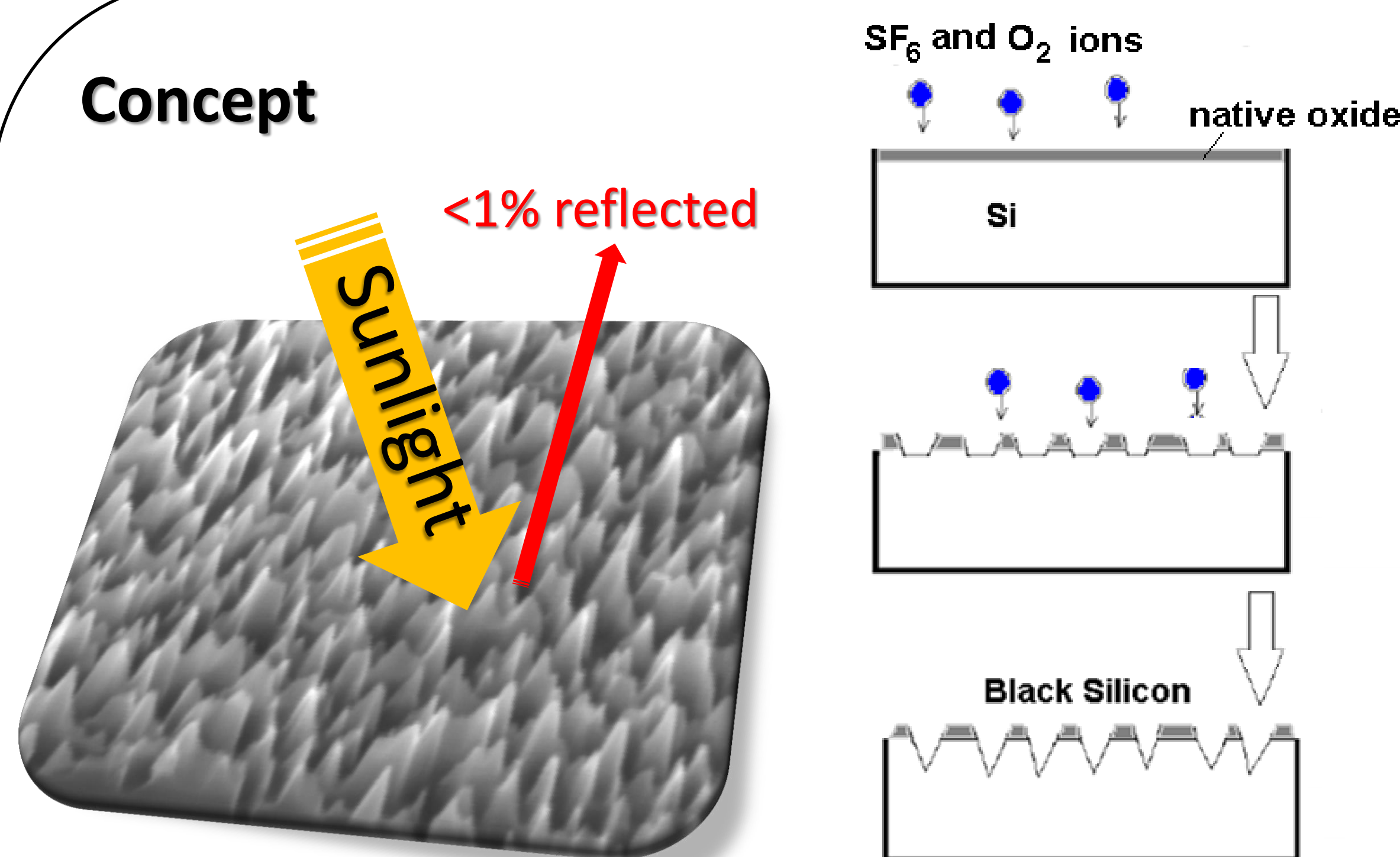
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Simulation and Measurement of Angle Resolved Reflectance from Black Si Surfaces

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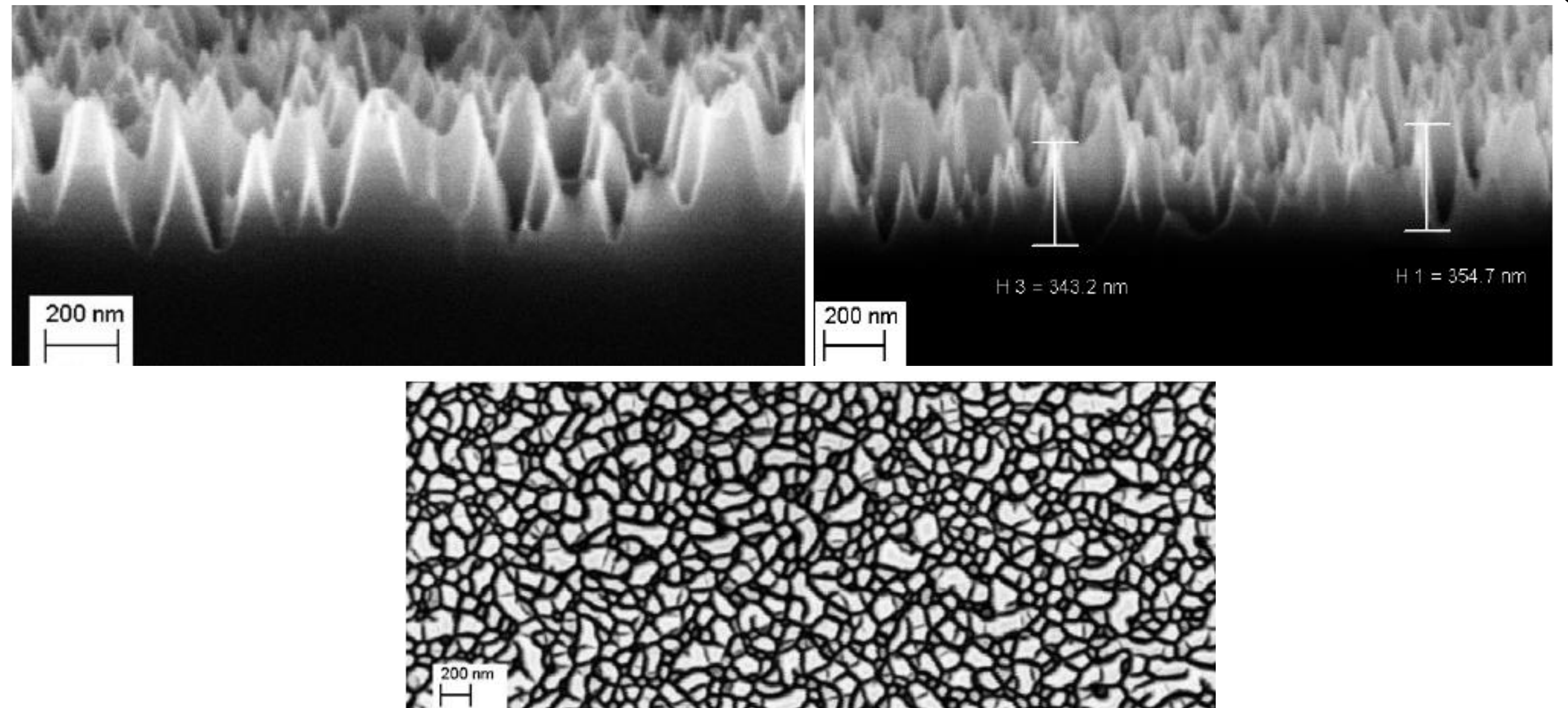
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Concept



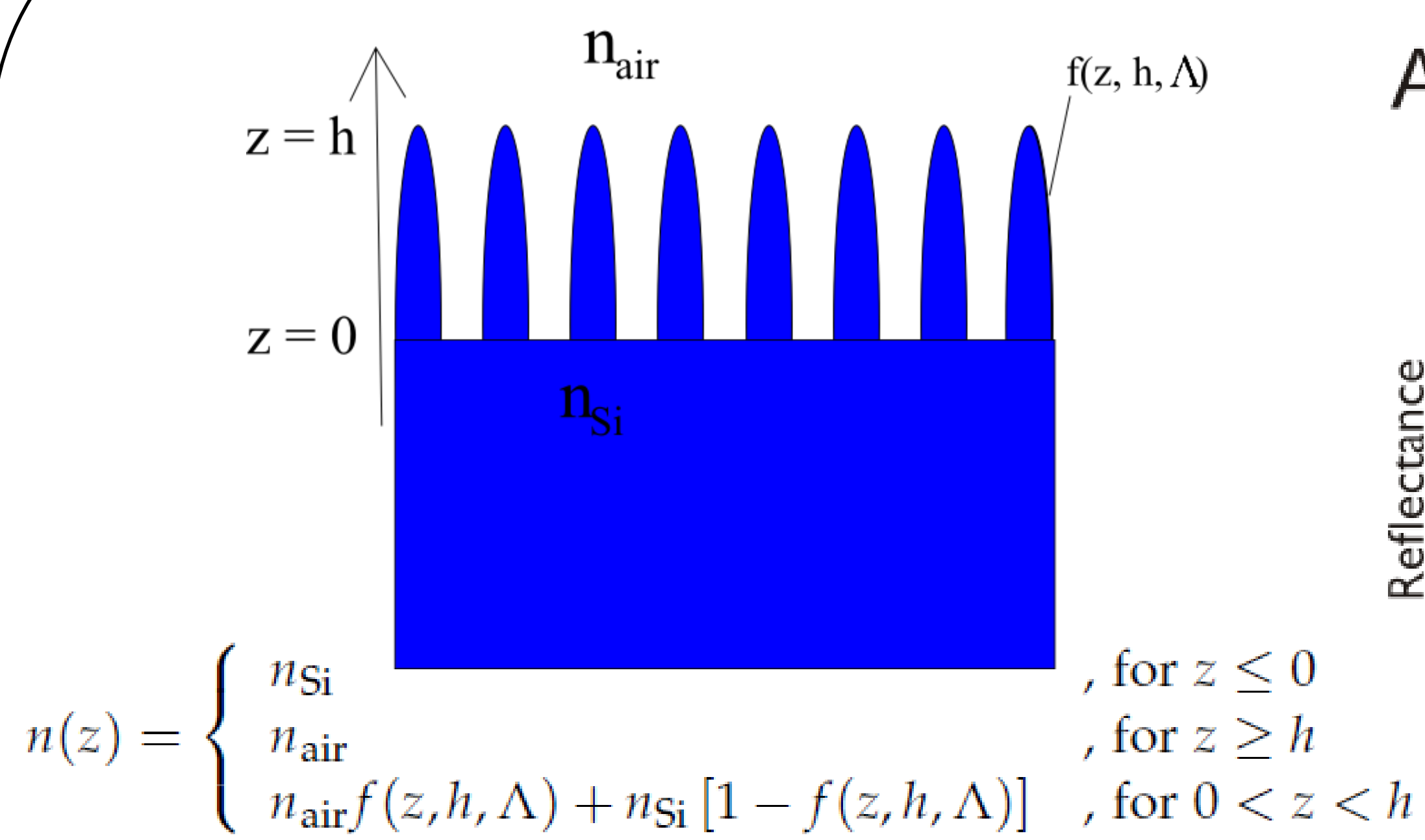
Black Silicon nanostructures suppress AM1.5G weighted, average reflectance from solar cell surfaces to less than 1%.

Nanostructures are fabricated by means of maskless reactive ion etching (RIE) using SF₆ and O₂ plasma.



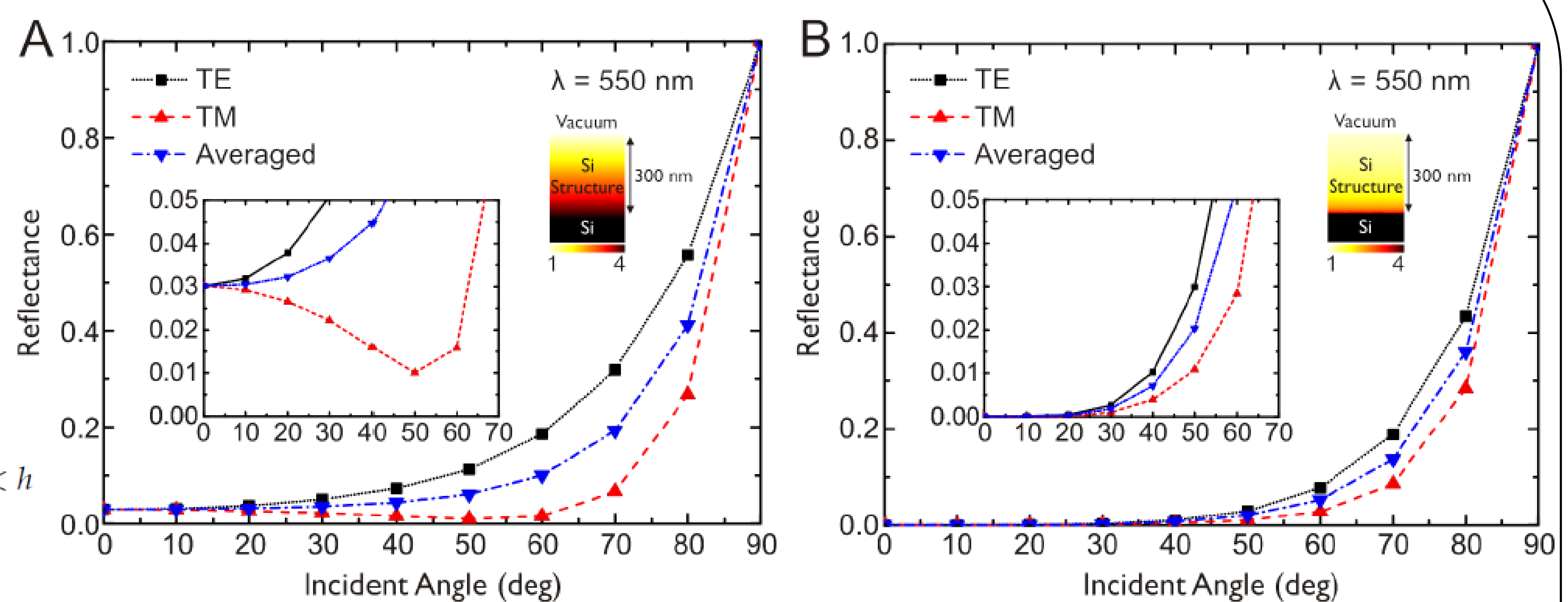
SEM-images at 45° (top) and 0° (bottom) of RIE-textured Si surfaces with 300 nm nanostructure height. The nanostructures represent approximately linear (top, left) and non-linear (top, right) graded refractive index profiles.

Simulation Method



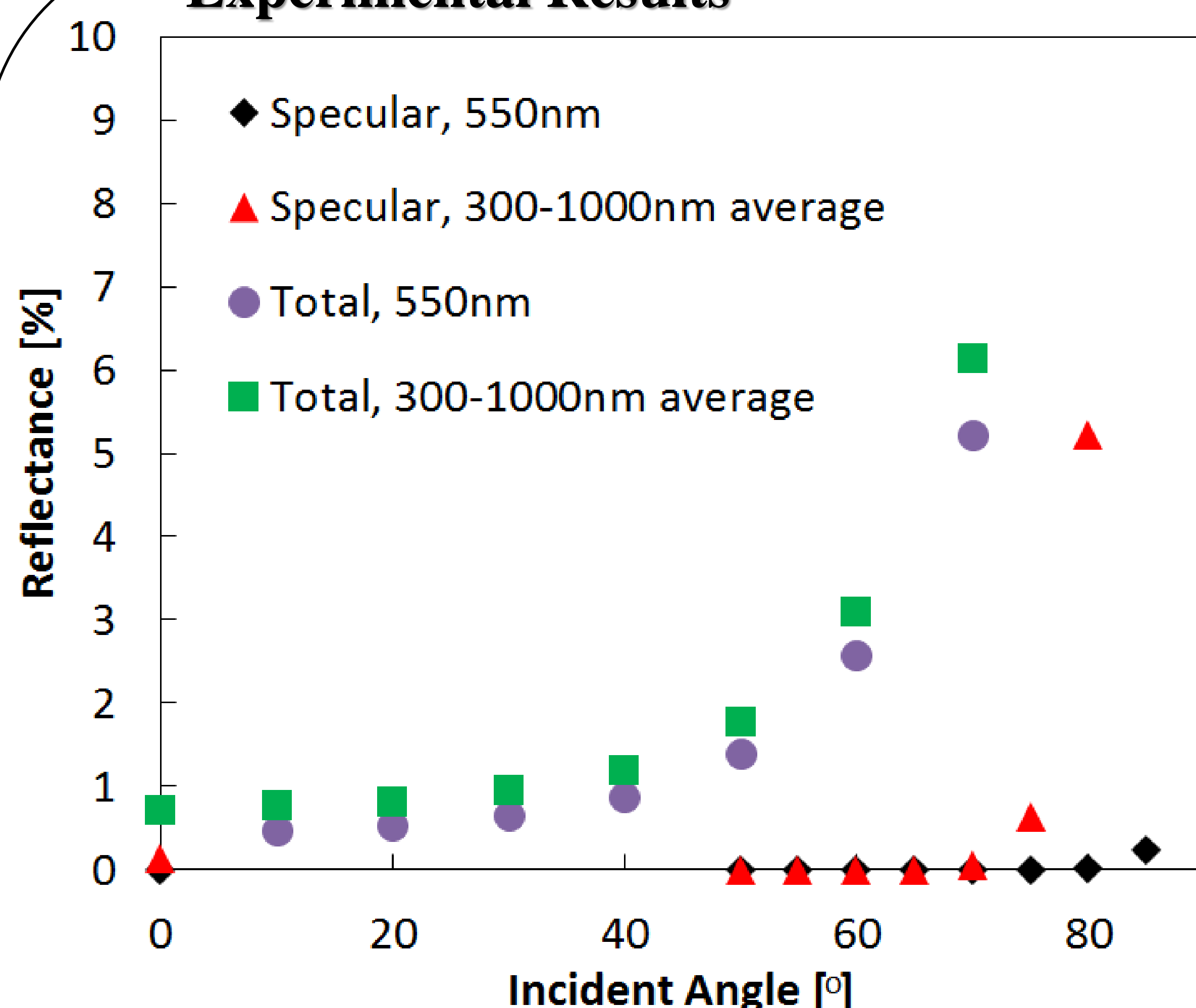
The nanostructure topology is modelled as a graded refractive index. Λ is a nonlinearity parameter. The index shape function was defined as $f(z, h, L) = \ln(1 + z/L) / \ln(1 + h/L)$ in case of a non-linear index profile and $f(z, h, L) = z/h$ in case of a linear index profile; here the parameters $L = 10$ nm and $h = 300$ nm were used.

Simulation Result

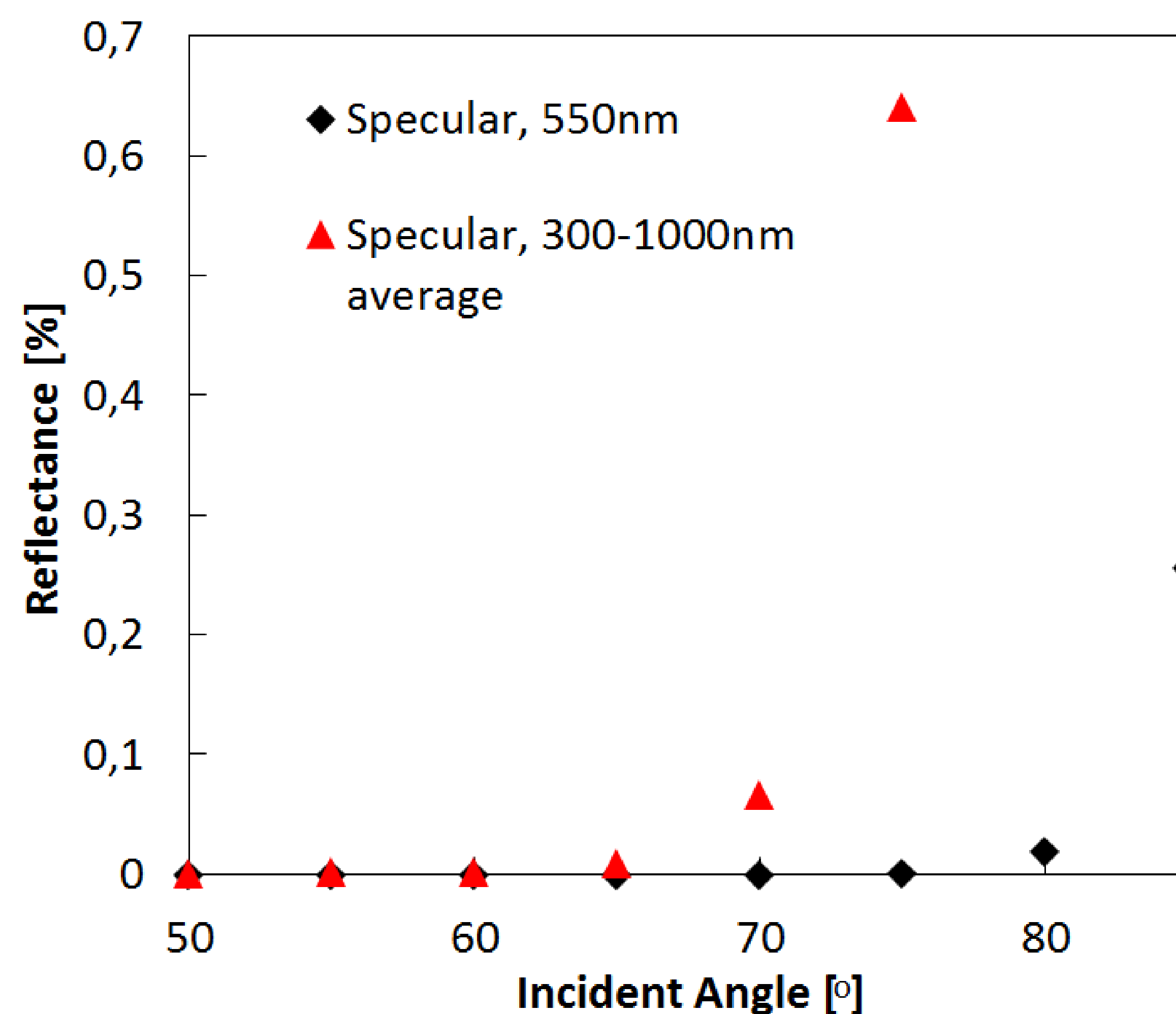


Simulated reflectance as function of incident angle at a wavelength of 550 nm for surfaces with nanostructures of 300 nm in height in case of (a) linearly graded refractive index and (b) non-linearly graded refractive index. The insets in (a) and (b) show the simulated reflectance at incident angles of 0-70°. The non-linear profile yields the lowest reflectance; below 1% for angles up to 45°.

Experimental Results



Experimental specular and total reflectance as a function of incident angle. The average reflectance in the wavelength range 300-1000 nm and the value at a wavelength of 550 nm are shown (left). The specular reflectance at incident angles from 50-85° is shown to the right.



Conclusion

Angle-resolved reflectance from nanostructured Si surfaces realized by maskless RIE texturing has been simulated and measured. In both simulation and experiment the specular reflectance is below 10% at incident angles below 65° and below 1% at incident angles below 45° in the case of non-linear graded refractive index. From the simulation results the non-linear graded refractive index yields lower reflectance than the linearly graded refractive index.